Reactions of Fatty Materials With Oxygen. XV. Formation of 9,10-Dihydroxystearic Acid and Cleavage Products in the Oxidation of Oleic Acid and Methyl Oleate in Acetic Acid²

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THE prolonged autoxidation of unsaturated fatty materials in the absence of solvents leads eventually to highly viscous products through which efficient dispersion of oxygen is extremely difficult (11). The obvious solution, namely, use of a diluent, is complicated by the problem of finding an "inert" material. Consideration of possible "inert" solvents, as well as examination of the literature, indicated that glacial acetic acid most nearly meets the requirements and, in addition, it possesses the characteristic of accelerating autoxidation reactions (1, 5, 13).

This paper describes the results obtained in the autoxidation of oleic acid and methyl oleate at 25-30°, 65°, and 115-120°C. in acetic acid solution with cobalt acetate (or occasionally cobalt oleate) as the catalyst. Samples were withdrawn at suitable time intervals, the acetic acid was recovered, and the non-volatile residue was worked up to isolate 9,10dihydroxystearic acid, short-chain cleavage products (mono- and dibasic), unoxidized and monohydroxy materials, and polymers.

Experimental

Materials Used. The oleic acid and methyl oleate (composition: oleic, 94-98%; linoleic, 0.3%; saturates, 2-6%) were prepared from olive oil (7). Cobaltous acetate and glacial acetic acid were analytical reagent grade. Cobaltous oleate was prepared from purified oleic acid as described previously (11).

Autoxidation Procedure. A typical experiment at 65° is described in detail. (Tables I, II, and III summarize the results obtained at 25-30°, 65°, and 115-120°). A solution consisting of 1,000 g. of oleic acid (or methyl oleate), 10.1 g. of cobaltous acetate (or 33 g. of cobaltous oleate), and 2,000 ml. of glacial acetic acid was prepared in a 5-1., three-neck flask equipped with a thermometer, a reflux condenser, and two fritted discs immersed in the solution. A vigorous stream of air or cylinder oxygen was passed through the solution while the temperature was maintained at 65°. Samples of the solution (ca. 450-500 ml.) were withdrawn at suitable time intervals for isolation and analysis of oxidation products.

The acetic acid was recovered under reduced pressure and the residue analyzed. The oxidation was stopped when the iodine number became substantially constant (5-10); this usually required 150-250 hours at 65°. The peroxide values were negligible throughout.

The residue was refluxed for six hours with an

excess of 6 N aqueous sodium hydroxide, acidified while hot with 6 N sulfuric acid, and stirred vigor-

¹Paper XIV is reference 10.

²Presented at the Fall Meeting of the American Oil Chemists' Society, Chicago, Ill., Nov. 2-4, 1953.

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ously. A dark brown viscous oil separated. After the mixture had cooled to room temperature, it was treated with ether and the aqueous layer was reextracted. The combined ether solutions, in which a considerable quantity of insoluble white solid was suspended, was washed three times with small quantities of water to remove excess sulfuric acid and salt. These washings were reextracted with ether, and all ether solutions were then combined. The ether: solute ratio was approximately 3:1 at this point. The ether solution was cooled to 0 to 5° and filtered, and the solid was washed once with a small amount of cold ether. The precipitate was substantially pure high-melting 9,10-dihydroxystearic acid, m.p. 129-130° and neutralization equivalent, 317-323. A mixed melting point with an authentic sample, m.p. 130-131°, showed no depression. The yield was 12-17%, depending on the oxidation time (Table II). [An additional 1-2% of slightly impure high melting 9,10-dihydroxystearic acid, m.p. 120-123°, could be obtained by evaporation of the ether, solution of the residue in acetone (5 ml. per g. of solute) and cooling to -20°, followed by recrystallization of the precipitate from 95% ethanol at 0°.]

The dark-brown viscous residue obtained after recovery of the ether was converted to methyl esters by refluxing for eight hours with a large excess of anhydrous methanol (sulfuric acid catalyst). These esters were distilled from a Claisen flask to a maximum pot temperature of 230°/0.1 mm. Two overhead fractions, b.p. 60°/4-160°/0.4 mm. and 140°/0.05-200°/ 0.1 mm. were taken. Results are summarized in Table II. Maximum yields of cleavage products were 64-68%; polymer yields were 11-22%.

Discussion

Tables I, II, and III summarize the results obtained in the oxidation of oleic acid at 25-30° (room temperature), 65°, and 115-120° (the reflux temperature of the reaction mixture), respectively.

At an oxidation temperature of 65° the yield of high-melting 9,10-dihydroxystearic acid remains fairly constant between 12-17% (Table II). At 25° (Table I) and 115-120° (Table III) the yield is lower during the oxidation periods studied. At 115-120° the yield increases from 2% after 4 hours of oxidation to 11% after 128 hours; at 25-30° the yield appears to reach a maximum of 16% after 500 hours and then drops.

The best yields (64-68%) of cleavage products are also obtained at 65° (Table II). Examination of the iodine and saponification numbers of the cleavage products obtained after 256 hours of oxidation indicates that unoxidized material probably does not exceed 10% of this fraction. On the other hand, at room temperature (Table I) or the boiling point (Table III) the yields of cleavage products are consid-

TABLE I Yields of Products Obtained in Autoxidation of Oleic Acid at 25-30° in Acetic Acid

Oxidation time, hours	High-melting 9,10-dihy- droxystearic acid			Cleavage products and unoxidized material a			Unox	cidized and	Polymeric residue ^c			
	Yield	Neut. equiv.	М.Р., °С.	Yield %	Sapon.	Iodine no.	Yield %	Sapon. no.	Iodine no.	Hydroxyl oxygen,%	Yield %	Mol. wt.d
100200	6 8	312 320	128 127	33 58	210 220	50 44	43 14	212 237	70 60	0.2 0.5	18 20	935 865
300 400	6	316 317	127 125	$\frac{21}{25}$	230 230 237	43 32 32	55 52 34	$248 \\ 250 \\ 238$	$64 \\ 64 \\ 44$	$0.6 \\ 1.7 \\ 1.8$	$\begin{array}{c} 22 \\ 16 \\ 20 \end{array}$	$ \begin{array}{r} 865 \\ 1,780 \\ 820 \end{array} $
500	16 11	$\begin{array}{c} 315 \\ 310 \end{array}$	$\begin{array}{c} 127 \\ 130 \end{array}$	23	374	17	45	240	51	1.9	19	2,600

a Boiling range, $60^{\circ}/4.160^{\circ}/0.4$ mm. b Boiling range, $140^{\circ}/0.05\cdot200^{\circ}/0.1$ mm. c Non-volatile at a pot temperature of $230^{\circ}/0.1$ mm. d Determined ebullioscopically in chloroform.

TABLE II Yields of Products Obtained in Autoxidation of Oleic Acid at 65° in Acetic Acid

Oxidation time, hours	High-melting 9,10-dihy- droxystearic acid				age produc xidized mat		Unox	idized and	Polymeric residue			
	Yield %	Neut. equiv.	м.Р., °С.	Yield %	Sapon. no.	Iodine no.	Yield %	Sapon. no.	Iodine no.	Hydroxyl oxygen,%	Yield %	Mol. Wt.
16 32 64	12 17 16	321 321 320	130 130 130	48 48 58	304 365 393	40 23 16	16 13 9	$206 \\ 217 \\ 216$	34 31 26	4.1 4.8 5.6	22 20 16	540 860 845
128 256	13 12	323 317	130 129	64 68	414 433	11 8	9 8	232 256	24 32	5.6 4.2	12 11	а

a Insoluble.

erably lower. At 100° the results are substantially the same as at 65°, but the oxidation time is shorter.

The formation of relatively large amounts of 9,10dihydroxystearic acid plus cleavage products at 65° (Table II) is necessarily accompanied by reduced yields of unoxidized, hydroxy, and polymeric materials, which is a desirable situation. On the other hand, at room temperature (Table I) and the boiling point (Table III) these last materials account for over 60% and 40%, respectively, of the starting material. Autoxidation at room temperature and the boiling point of acetic acid are therefore inefficient techniques for the preparation of 9,10-dihydroxystearic acid or cleavage products. At 65° however approximately 80% of the original oleic acid can be accounted for as desirable products. Since we have shown qualitatively (8) that the polymeric residue also yields cleavage products on reoxidation, the overall conversion is fairly high.

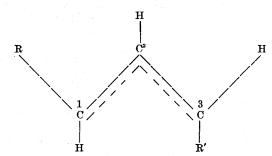
Separation of the cleavage products by conventional methods (saponification of the mixed methyl esters, acidification, steam distillation, reesterification with methanol, and fractional distillation) shows that they consist mainly of methyl esters of \hat{C}_{e} - \hat{C}_{12} monoand dibasic acids. Unfortunately their precise chainlength distribution is not known because of handling losses and the relatively small quantities available by the time the analytical distillations were carried out. Based on the present data, methyl esters of C₈-C₁₀ acids appear to predominate as would be expected (3, 9).

Oxidation at 65° proceeds more rapidly than at 25-30° or 115-120°. The surprisingly slow rate of oxidation at 115-120° is probably a consequence of the lowered solubility of oxygen in boiling acetic acid as well as the poor contact between oxygen and the substrate because of acetic acid vapor.

In general, the molecular weights of the polymeric residues are about 800-1,100 with occasional samples in the range of 1,800-2,600. Products partially insoluble in boiling chloroform were also encountered from time to time. No further examination of the polymeric residues was conducted.

The 9,10-dihydroxystearic acid isolated from the saponified, acidified autoxidation mixture is the highmelting isomer, it has a sharp melting point, usually not below 128°, and its purity is obviously high. This is indeed surprising in view of the complexity of autoxidation reactions and the known shifting of double bonds which takes place.

The most likely precursor of high-melting 9,10dihydroxystearic acid is trans-9,10-epoxystearic acid, which Ellis (3) has shown to be formed in about 20% yield by autoxidation of either oleic or elaidic acid. The fact that both a cis and a trans olefinic compound yield the same product is striking confirmation of our earlier proposal (6) that the majority of the radicals in the autoxidation of oleic (or elaidic) acid take the configuration shown below,



add oxygen at carbon atom 3 and become a trans hydroperoxide which would be a mixture mainly of 9-hydroperoxido-trans-10-octadecenoic acid (I) and 10-hydroperoxido-trans-8-octadecenoic acid (II) (10).

$$CH_3-(CH_2)_6-CH=CH-CH-(CH_2)_7-CO_2H$$
 (I)

$$CH_3-(CH_2)_7-CH-CH=CH-(CH_2)_6-CO_2H$$
 (II)

Cleavage of the -O-O- bond would yield HO. and RO. (III and IV). This type of unimolecular peroxide decomposition would be expected when hy-

					The Doming Meetic Acid (115-120)								
Oxidation time, hours	High di	-melting 9, roxysteario	10-dihy- acid	Cleavage products and unoxidized material			Unoxidized and hydroxy material			Polymeric residue			
	Yield %	Neut. equiv.	М .Р., °С.	Yield %	Sapon. no.	Iodine no.	Yield %	Sapon.	Iodine no.	Yield %	Mol. Wt.		
4	2 3 4 7 9	326 321 320 321 320	129 129 130 128 129 129	81 74 72 62 50 43	199 211 210 236 317 356	79 73 70 59 34 22	8 9 9 6 14	210 213 208 217 210 231	66 71 47 51 47	8 14 15 24 26	1,090 a 1,055 855 800		
* Insoluble.							11	231	40	31	735		

droperoxide concentration is low (1a), as is the case when cobalt salts are present.

$$CH_{\mathfrak{d}}-(CH_{\mathfrak{d}})_{\mathfrak{d}}-CH=CH-CH-(CH_{\mathfrak{d}})_{\mathfrak{f}}-CO_{\mathfrak{g}}H \tag{III}$$

$$CH_3-(CH_2)_7-CH-CH=CH-(CH_2)_6-CO_2H$$
 (IV)

Both III and IV, merely by a shift of one π-electron of the double bond to couple with the odd electron on oxygen, could form the oxirane ring in the 9,10position as shown (V and VI).

$$CH_3-(CH_2)_6-CH-CH-CH-(CH_2)_7-CO_2H$$
 (V)

$$CH_3 - (CH_2)_7 - CH - CH - CH - (CH_2)_6 - CO_2H$$
 (VI)

Reacquisition of a hydrogen atom by V or VI would yield the identical compound, namely, trans-9,10epoxystearic acid, the product actually isolated when solvent is absent (3). In acetic acid however trans-9,10-epoxystearic acid is converted by ring opening to the hydroxyacetoxy compound which yields highmelting 9,10-dihydroxystearic acid on hydrolysis.

This reaction scheme also accounts for the isolation of triol, reported by earlier works for other systems (4), since the reacquisition of the HO· by V or VI followed by hydrolysis would yield a trihydroxy compound.

It should not be concluded however that highmelting, 9,10-dihydroxystearic acid is the sole dihydroxy compound formed although there is no doubt that it predominates. It has been shown by us (11), as well as by others (3, 12), that low-melting 9,10dihydroxystearic acid is also formed. In the present investigation a 0.5-1% yield of low-melting 9,10-dihydroxystearic acid, m.p. 92° (a mixed melting point with an authentic specimen, m.p. 95°, was not depressed), was obtained from the fraction consisting of unoxidized and hydroxy material (Tables I, II, III) by saponification, acidification, and crystallization of the mixed acids successively from acetone and alcohol at 0°.

The isolation of only minor quantities of low-melting 9,10-dihydroxystearic acid strongly suggests that the formation of oxirane compounds does not occur by an epoxidation reaction between a peroxide and an olefinic compound. If epoxidation were an important reaction, appreciable quantities of cis-9,10-epoxystearic acid (solvent-free system) or low-melting 9,10dihydroxystearic acid (acetic acid system) would be

isolated since oleic acid, a cis compound, is the predominant olefinic species present during the major portion of the autoxidation reaction, and epoxidation is known to be stereospecific. Furthermore elaidic acid cannot be present to any significant extent since we have shown (10) that the bulk, if not all, of the trans components formed during the autoxidation of oleic acid are trans peroxides and not the simple trans olefinic compound. Recently we have obtained more direct evidence that elaidic acid is not formed in significant quantities by demonstrating that the products isolated from the urea complexes obtained in separating unoxidized material from peroxides (in solvent-free autoxidation systems) are substantially free of trans materials (2).

Summary

The autoxidation of oleic acid and methyl oleate in acetic acid solution at 25-30°, 65°, and 115-120° with a cobalt salt as catalyst has been studied. Samples were withdrawn at intervals and the oxidation products were analyzed and then separated into highmelting 9,10-dihydroxystearic acid, cleavage products, unoxidized and hydroxy materials, and polymers.

The best yields of desired oxidation products were obtained at 65°. Yields of pure 9,10-dihydroxystearic acid, m.p. ≥128°, were 12-17% and cleavage products 64-68%, thus accounting for about 80% of the starting material. At 25-30° and 115-120°, yields of the above-mentioned products were low.

A mechanism is proposed which accounts for the formation of trans-9,10-epoxystearic acid from both oleic and elaidic acid autoxidized in the absence of solvent, and the consequent isolation of high-melting 9,10-dihydroxystearic acid when acetic acid is the solvent.

REFERENCES

- 1a. Bateman, L., and Hughes, H., J. Chem. Soc., 1952, 4594-4601.
 1. Bolam, T. R., and Sim, W. S., J. Soc. Chem. Ind., 60, 50:56 (1941).
 2. Coleman, J. E., unpublished results.
 3. Ellis, G. W., Biochem. J., 30, 753-761 (1936).
 4. Farmer, E. H., and Sundralingam, A., J. Chem. Soc., 1942, 55 (200 C. and Phila.)

- 4. Farmer, E. H., and Sungraingam, A., J. Unem. Soc., 1942, 121-139.
 5. Gee, G., and Rideal, E. K., J. Chem. Physics, 5, 794-801 (1937).
 6. Knight, H. B., Eddy, C. R., and Swern, D., J. Am. Oil Chem. Soc., 28, 188-192 (1951).
 7. Knight, H. B., Jordan, E. F. Jr., Roe, E. T., and Swern, D., Biochemical Preparations, 2, 100-104 (1952).
 8. Knight, H. B., and Swern, D., unpublished results.
 9. Ross, J., Gebhart, A. I., and Gerecht, J. F., J. Am. Chem. Soc., 71, 282-286 (1949).
 10. Swern, D., Coleman, J. E., Knight, H. B., Ricciuti, C., Willits, C. O., and Eddy, C. R., J. Am. Chem. Soc., 75, 3135-3137 (1953).
 11. Swern, D., Knight, H. B., Scanlan, J. T., and Ault, W. C., J. Am. Chem. Soc., 67, 1132-1135 (1945).
 12. Swift, C. E., and Dollear, F. G., J. Am. Oil Chem. Soc., 25, 52-53 (1948).
 13. Ueno, S., Okamura, Z., and Saida, T., J. Soc. Chem. Ind. Japan, 34, Suppl. binding 106-108 (1931).